(NASA-CR-120606) TEST REPORT SEPS SOLAR ARRAY ROOT SECTION MODEL (Lockheed Missiles and Space Co.) 50 p HC $3.75 CSCL 10A

N75-16085

Unclas
G3/44 09794

[redacted]

Lockheed

MISSILES & SPACE COMPANY, INC.

A SUBSIDIARY OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CA

LMSC-D384268
6 December 1974

TEST REPORT
SEPS SOLAR ARRAY
ROOT SECTION MODEL

SEPS SOLAR ARRAY
TECHNOLOGY EVALUATION PROGRAM
Contract NAS8-30315

Prepared for
Marshall Space Flight Center
Huntsville, Alabama

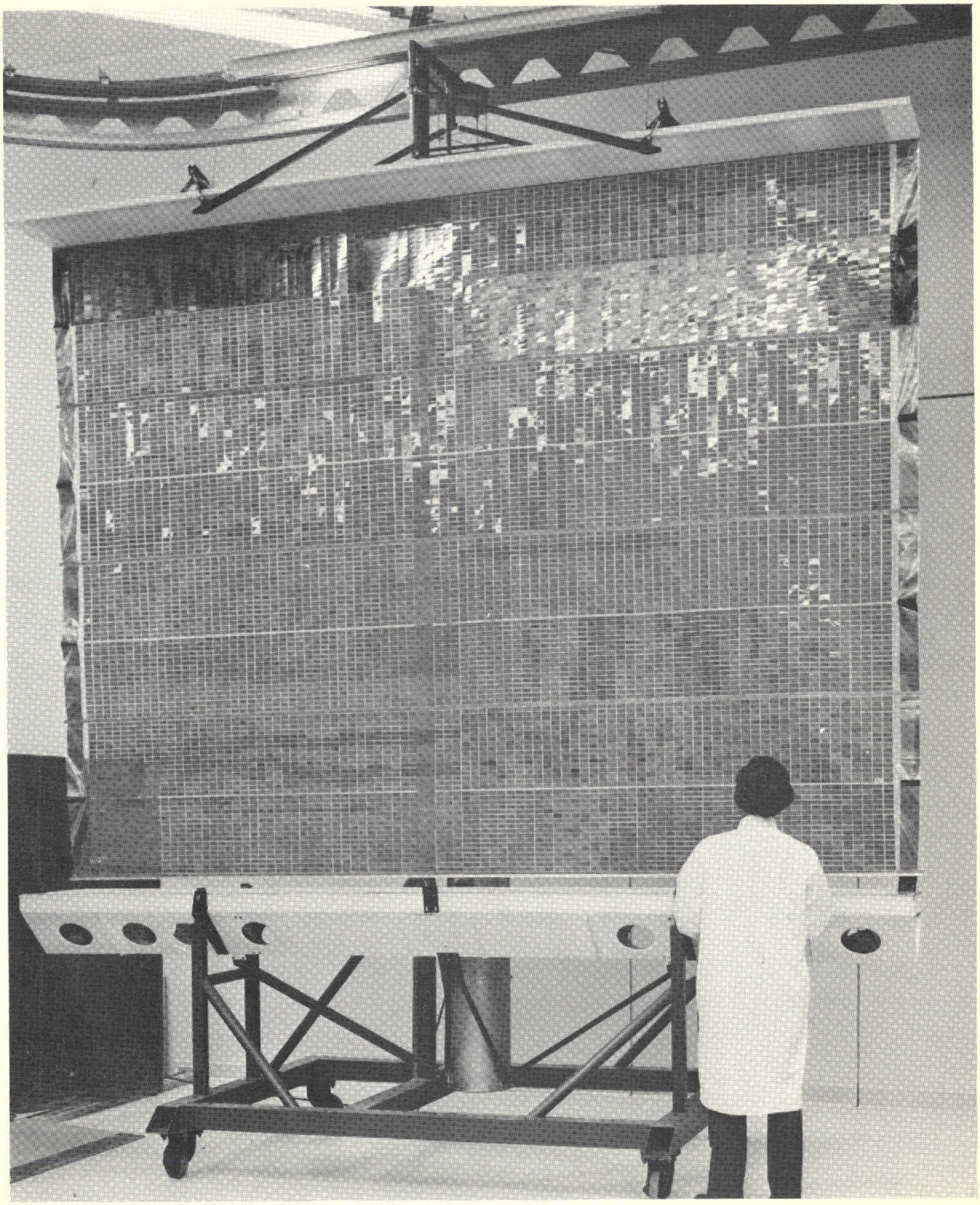
by

Space Systems Division Electrical Power Systems

LOCKHEED MISSILES & SPACE COMPANY, INC.

FOREWORD

The SEPS Solar Array Technology Evaluation Program included the fabrication and test of a solar array functional root section model to verify preliminary array design concepts developed during the program. The root section model is full scale width, 160 in., and contains a model array blanket that is 10 feet long. The blanket contains 1/8 live electrical modules and the remainder contains solar cell mass simulators. A storable Astromast is used for array blanket extension and retraction. This report describes the model component and system assembly hardware, tests and test results.



Root Section Model

1.0 SUMMARY

The tests performed on the SEPS solar array model fall into two categories:

1) Examinations to verify and document the dimensions, weight, electrical continuity, and electrical resistance of model components.

2) Extension/retraction tests to verify and document the correct functional operation of stored blanket preload application, preload release, tensioning of guide wires, intermediate tension application, inboard end tension application, on-array padding solar cell protection, integration of the FCC harness with the blanket, mast straightness, mast operation to and from full and partial retraction, and changing of intermediate tension location in the model blanket.

Examinations and extension/retraction tests were performed on the model mast by itself and on the model containment box preload assembly without the mast attached. Extension/retraction tests were then performed on the assembled model.

1.1 Extension Mast Tests

The tests of the continuous longeron 10 in. diameter Astromast were successful except for two anomalies which required mast repair operations. The first was a longeron failure during acceptance testing which occurred under maximum load at near full extension (12 feet). The failure was ascribed to a roller not properly engaging the vertical guide rail in the mast deployment nut. Wear on the entrance to the Delrin guide rails and deformation of washers on the longeron fixture assemblies was observed. The longeron was replaced, the guide rail entrances were faired and the washers were provided additional support. The second failure was the shearing of a roller shaft on the second set of rollers from the top of the mast. This failure was caused by the improper wiring of the "full closed" limit switch into the mast electrical controls and several hard closures of the mast tip dust cover against the top flange of the mast canister. The roller was replaced by adhering a small plate with an axle to the longeron fitting and reducing the roller width to compensate for the added small plate width.

1.2 Electrical Tests

The xenon pulse simulator tests of the two 765 cell modules in the array blanket and the separate 255 cell module revealed larger than expected assembly degradation. Additional weld schedule development for the one ounce copper interconnect system and better cell contact metallization thickness control are required. The I-V curve of one of the 765 cell modules indicated that one of the cells was open and the module was tested in a dark thermal image test using a Dynarad Thermal Imager. This method of testing was partially successful and further development appears worthwhile.

1.3 Model Assembly Tests

The extension/retraction tests of the assembled model in one "g" verified the proper operation of the panel hinge design, the harness integration with the panels, the blanket tensioning systems, and the extension mast integration with the array containment box and the array preload mechanism. The preload locking mechanism did not operate properly during the last stages of array retraction. This mechanism was redesigned and installed. The design now operates properly.

Rolling of the array blanket in one "g" during deployment was observed. This action is the movement of the panel foldline from the front of the containment box through the lower half of panel as this half rises in the array plane (similar to a bedspread being pulled back to uncover a bed). By installing vertical 0.25 in wide, 0.016 in. thick Be-Cu stiffening strips in 5 places across the back of the lower halves of the 4 panels, the radius of the rolling fold was significantly increased, thereby reducing the stresses in the panels.

During retraction of the array blanket in one "g", manual assistance is required at both edges of the blanket to guide the panel fold line to the front of the containment box.

The two electrical modules making up one half of the top panel react differently from the mass simulator panels. They are somewhat stiffer and hang flatter than the mass simulators.

CONCLUSIONS

The SEPS Solar Array Model fabrication and testing provided a demonstration of the handling of the largest (30" x 157") and lightest flexible solar array panel hardware yet attempted. The design concepts for panel hinging, intermediate blanket tensioning, electrical harness integration and use of the extension mast for actuation of the blanket preloading, release, extension, retraction and application of blanket preload were validated.

Vertical deployment in one "g" of both electrical and mass simulator panels of the SEPS lightweight design requires panel stiffening to ease the amount of stress placed in the panel components as they move from a flat horizontal position in the containment box to a vertical position in the extending blanket.

Vertical retraction in one "g" with hands off will require modifying the panel stiffening design to 1) insure that the panel foldline along its total length breaks forward away from the hinge side of the containment box and that the foldline falls or rolls out to the front of the containment box. The hardware weight requirement may be too high for flight operation and a lighter weight design may not work hands off in a one "g" vertical test. Horizontal and/or neutral buoyancy testing of components will be required to verify that the flight design will fold properly. The root section model hardware might serve that purpose.

While a contoured thickness honeycomb box cover may be used to keep the top of the blanket in line (no droop at ends), an improved design will use the four locking levers as tension members in the extended array position. They will assume some of the blanket tension load and keep the top of the blanket in line. The model uses a whiffle-tree in the counterbalance system for this purpose.

2.0 TEST SPECIMEN AND TEST AID DESCRIPTION

The test specimen is a 10 foot tall section of the SEPS Solar Array that is full scale width (157 in.). The model consists of the array containment box, 10 feet of array blanket, the inboard 10 feet of the array harness design, the guide wire and tensioning system and a model extension mast. The materials used in the model are of flight design except where significant cost savings are achieved by substitution of materials. The model is functional where function is required to validate the proposed design. The array blanket is flight weight and contains two electrical modules that are each 6.75 ft^2 in area. The remainder of the blanket area contains glass slide solar cell mass simulators.

The test aids include a one "g" Counterbalance System that prevents overloading the model extension mast, a support structure which holds the combined extension mast/ array containment box assembly in a vertical position, and a hand held Model Control Box that contains the necessary switches to control the operation of the model extension mast. The LMSC xenon pulse solar simulator facility was used to test the two electrical modules for the model blanket and the smaller third module that was delivered separately.

2.1 Model Components

2.1.1 Extension Mast

The model extension mast is a 12 ft. long, 10 inch diameter coilable lattice, continuous fiberglass longeron Astromast. The mast element is entirely stored in a mast canister. The canister also contains a mast extender/retractor mechanism that is driven by two electric motors. Upon command, the extender mechanism will extend the mast to the fully extended length or any fraction thereof. The mast extension and retraction rate has the capability of being varied infinitely over the range of 1 in/sec to 4 in/sec. The total component weight is 36 pounds. The mast will provide a 30 lb. extension and retraction force from the beginning of extension to the end of retraction. A 30 lb. load will be supported at 6 inches outside the flat surface of the beam horizontal triangular cross section throughout the extension-retraction cycle.

2.1.2 Array Blanket

The model blanket is composed of four panels that are each 13.1 ft. wide and approximately 30 inches tall. The panels are hinged to each other along their 13.1 ft. long edges to form a blanket that is 10 ft. tall. Each hinge contains two grommets through which the array guide wires are passed. Two electrical modules are contained in the blanket. Each module is the size of one-quarter of a panel and contains 765 2 x 4 cm 200 micron (8 mil) silicon solar cells with wraparound contacts. The contacts are passivated Ag-Ti. The cells are covered by 150 micron (6 mil) fused silica coverglasses with AR coatings and blue filters. The cells are parallel gap electric resistance welded to a 1 oz. copper printed circuit interconnect system. The interconnect system is encapsulated between two sheets of 0.5 mil Kapton/0.5 mil high temperature polyester adhesive (CMC-122-1/2-1/2) in a laminated structure. A molded in-place RTV-41 silicone rubber on-array padding design is used in the right hand half of the model blanket. The padding is 0.032 x 0.032 in. in cross-section and is located between each solar cell and cell mass simulator on the face of the panels. The padding runs only vertically or only horizontally on half panels such that folded facing half panels form a criss cross padding configuration. The left half of the model blanket employs no on-array padding. The two electrical modules (1/4 panel) are in the top panel, one on left, with no padding, and one on the right with on-array padding.

The remainder of the blanket panels is composed of a single layer of 2 mil mylar plastic film. Three hundred fifty (350) micron (14 mil) 2 x 4 cm glass slides are used as solar cell mass simulators and are attached to the mylar film with double backed adhesive tape. The blanket contains 1530 electrical cells and 10,710 mass simulators. The panel hinges are composed of 5 mil thick FEP Teflon impregnated fiberglass cloth that are formed in a loop and glued to the panel edges. The loops are cut to allow interlocking of hinge material to provide a piano hinge configuration. A solid 0.032 in. steel piano wire is used as the hinge pin.

The first 10 feet of the array design harness (the inboard end of the array) is an aluminum FCC cable assembly that is attached to the two opposite vertical edges of the array blanket. The harness is truncated at the top of the model blanket. The harness is joined to the three electrical modules by an Alusol solder technique for joining aluminum to the copper interconnect system. An additional 10 feet of harness assembly is led into the triangular support beam for the containment box.

2.1.3 Containment Box

The model array containment box is full size. It is composed primarily of two honeycomb panels. One forms the bottom of the box and the other is the box cover. The array blanket is preloaded for launch load protection by compressing the blanket between the box cover and box bottom. The box cover has a cover preload assembly attached to it. This assembly of levers is actuated by the extension mast through a mast tip assembly that is attached to the cover preload assembly. The sides of the box are a perimeter shield and are of lightweight sheet metal construction as is the structure under the box bottom that provides torsional stiffness around the box longest dimension.

Since the 4 panel model blanket is under 10 percent of the preliminary design blanket, the missing stowed blanket volume is represented by a raised false floor (aluminum honeycomb panel). The model containment box assembly weighs 78 lbs.

2.1.4 Tensioning and Guide Wire System

The Guide Wire system consists of two wires (0.025 inch dia. stainless steel cable) that are connected to the box cover at one-fourth of the box cover length in from the cover ends. The other end of a guide wire is stored on a reel that is controlled by a negator assembly. The two negators allow the guide wires to feed out as the box cover rises during mast extension and keeps each wire under a constant 1 pound tension. The guide wires are similarly reeled in under constant tension as the array blanket is lowered. The guide wire negators and wire storage reels are attached to the under side of the containment boc bottom. A fair lead pulley allows a wire coming off a horizontal reel to turn 90 degrees upward and to pass through a hole in the box bottom.

The tensioning system consists of an intermediate system and an array bottom edge system. The intermediate system is similar to the guide wire system except that the outboard ends of the wires are attached to an intermediate tension distribution bar. This bar is integrated with the hinge between the panels and can be located at any of the three between-panel hinges. Each tension wire has its storage reel and negator installed on the underside of the containment box bottom. A 1 pound tension force is applied to the intermediate tension wires as the intermediate tension distribution bar leaves the containment box during array extension. This tension is placed in the array blanket above the bar and is released only when the bar returns to the box during array retraction.

The array bottom edge tensioning system is similar to the intermediate system except that the two wire outboard ends are attached to the array bottom edge tension distribution bar. A constant six pounds of tension is applied by each of the two bottom tension negators as soon as the bottom tension distribution bar leaves the bottom of the box. This tension is placed on the entire blanket and is removed only when the retraction of the array mast allows the bottom bar to return to the bottom of the containment box.

2.1.5 Root Section Model

The root section model is an assembly of the above components. The operation of the extension mast motors and the negator systems provide for the extension, retraction, preloading and tensioning of the model array blanket. The model is shown in Figure 1 in the retracted position. The tall mast is the support for the one "g" extension counterbalance system. The model is illustrated in Figure 2.

2.2 Test Aids

2.2.1 Solar Pulse Simulator

The simulator is a TRW pulsed xenon solar simulator which illuminates a 4' x 4' horizontal test plane. The facility also has a lamp station that illuminates a 8' x 8' vertical test plane. Illumination tests were performed at room temperature and AMO light conditions.

2.2.2 One "g" Extension Counterbalance System

This test aid is a two pulley and single counterbalance weight system that partially unloads the extension mast when the counterbalance line is attached to the box cover. This system is required in one "g" environment model extension testing since the model mast will not support the fully extended blanket (22 lbs.), the guide wire and tensioning system tensions (16 lbs.) and the weight of the box cover and preload

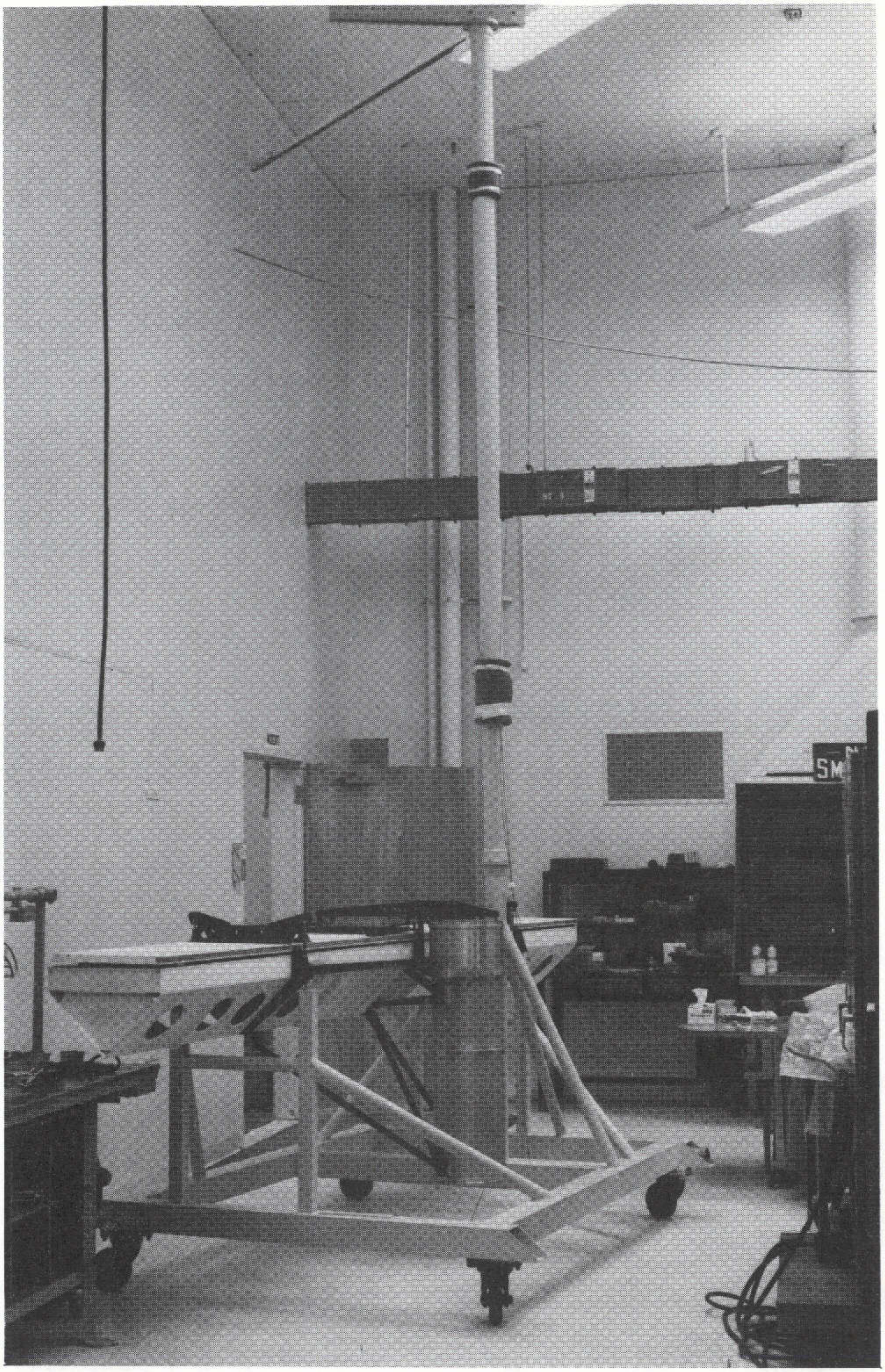


Figure 1 SEPS Solar Array Model and Support Structure

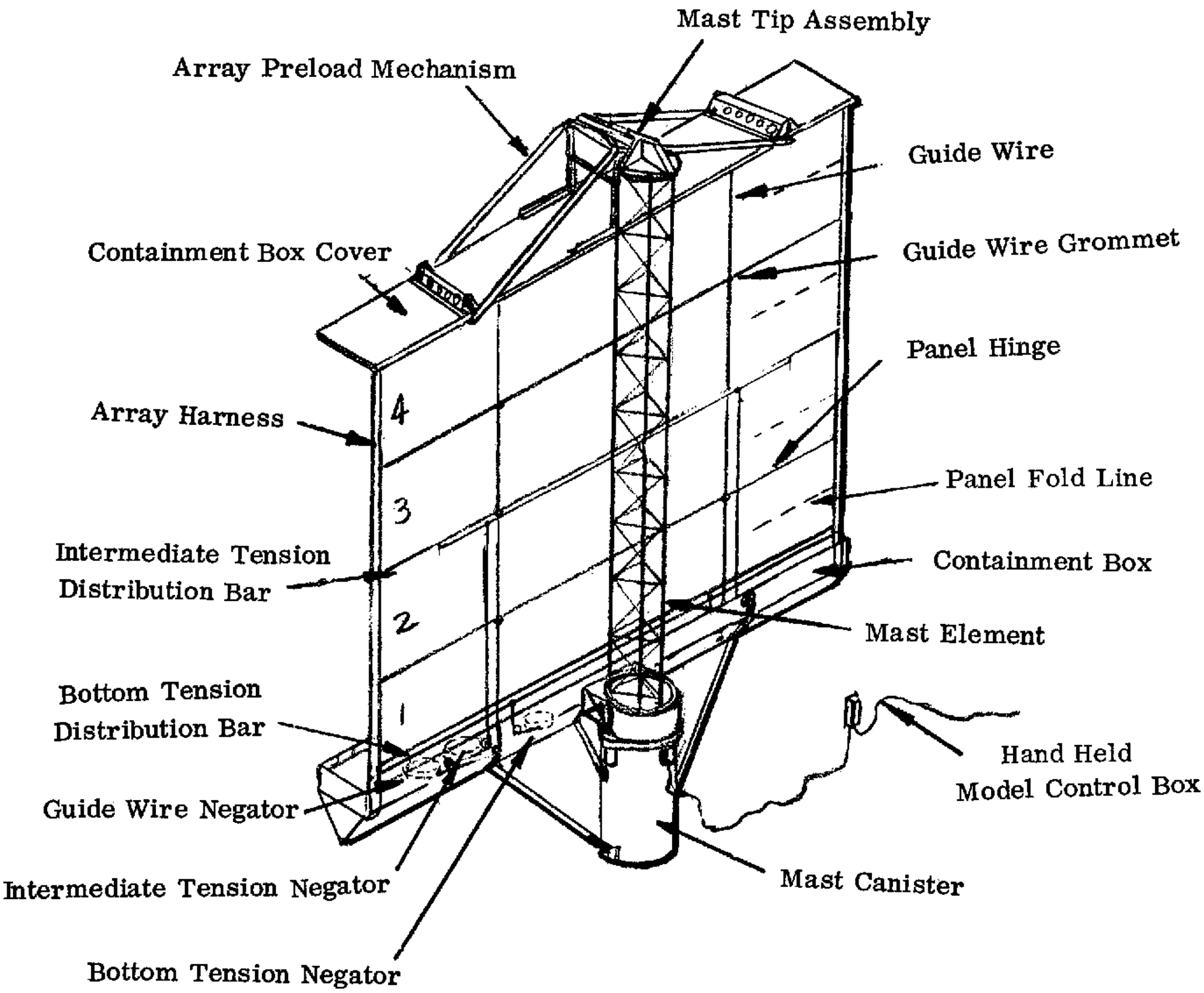


Figure 2 SEPS Solar Array Root Section Model

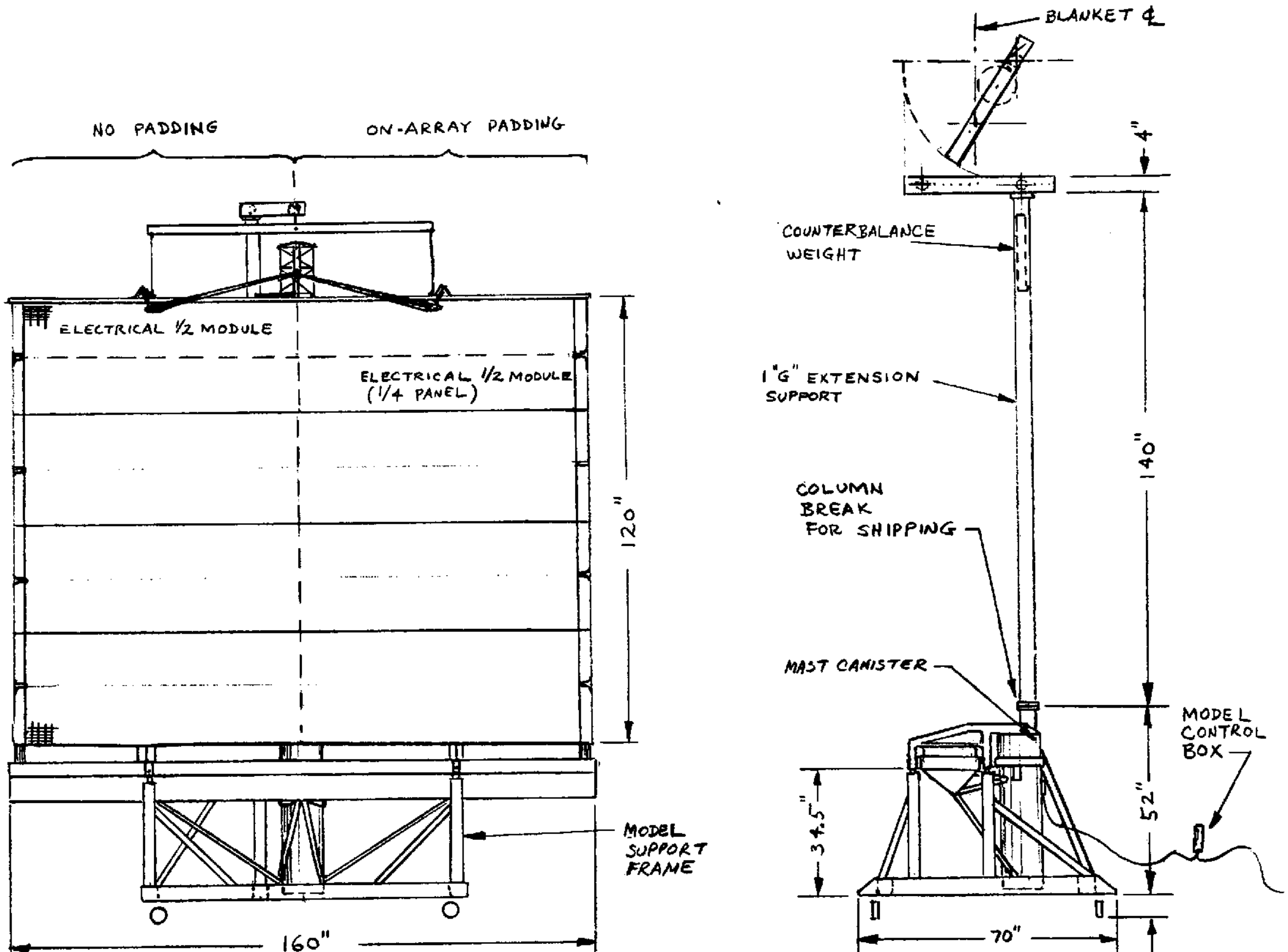


Figure 3 SEPS Solar Array Model Support Structure

assembly (45 lbs.). The first counterbalance pulley is located over the containment box at a height above the 12 foot extension height of the mast. The counterbalance line leads from the box cover upward and then over the first pulley, then horizontally to the second pulley and down to the attached counterbalance weight. The two pulleys are separated horizontally to assure that the weight is not over the model. The two pulley system is attached to a separate vertical stanchon that is self contained in the model support structure. The counterbalance weight is 55 lbs.

2.2.3 Model Support Structure

The model assembly of the mast canister and containment box is not in a stable configuration when positioned for vertical deployment of the mast. The model support structure holds the model and supports it such that a significant and unlikely force magnitude will be required to tip the model in any direction (Figure 3).

2.2.4 Model Control Box

The model control box contains the switches that take input power from a power supply and supply power to the mast extension motor. It controls

a. Power ON/OFF (RUN-STOP)
b. Mast movement direction - extend, retract.
c. Command stop at partial retraction position towards which mast is moving.

Limit switches on the model will 1) terminate motion toward a commanded position and 2) prevent initiation of motion commanded that exceeds full extension or full retraction. The power supply output voltage determines the mast extension and retraction rates.

3.0 EXTENSION MAST TESTING

3.1 Examination

The SEPS Model Extension Mast is shown in Figure 4. The overall dimensions of the mast are shown in Table 1 and the mast weights are shown in Table 2.

TABLE 1

MODEL MAST DIMENSIONS

Item	Actual Dimension	Nominal Dimension
Overall canister height	40.26	40.14 in.
Top plate to top of upper mounting pad	10.56	10.50 in.
Upper to lower mounting pad	26.50	26.50 in.
Diameter of upper nut flange	11.73	11.75 in.
Diameter of transition 1) and storage cylinder 2)	1) 10.98 2) 10.98	10.98 in.
Maximum width of gear guard	17.47	17.49 in.
Minimum width of gear guard	12.38	12.33 in.
Angles between mounting pads	137°	137.42°
Extended length of boom	144.1	144 in.

TABLE 2

MODEL MAST WEIGHTS

Item	Weight - Lbs
Overall model weight	35.96
Weight of boom without end plates	3.02
Weight of canister plus end plates	32.94

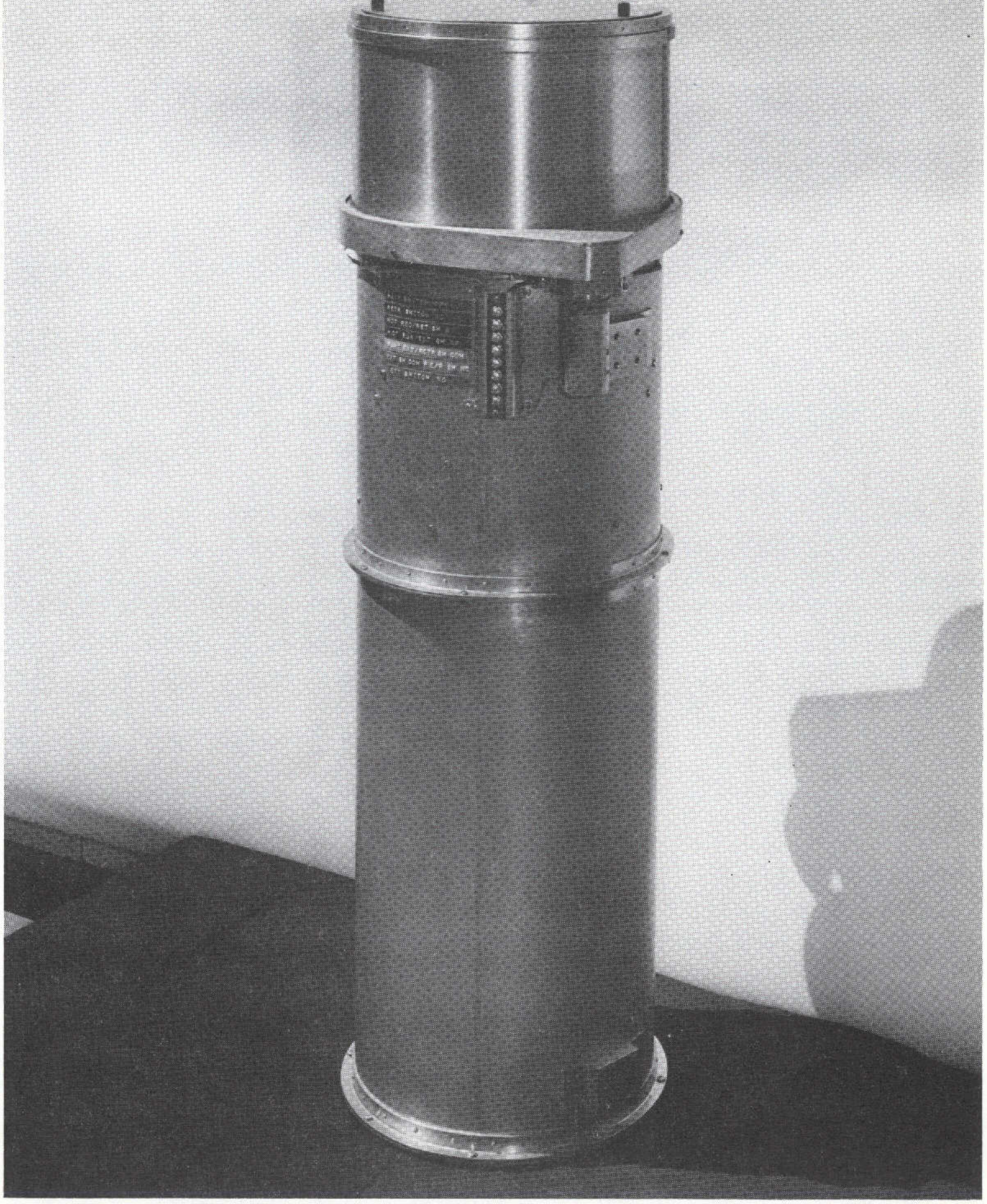


Figure 4 SEPS Model Extension Mast

The continuity and function of the electrical circuits of the mast were checked. The results of this examination and the circuitry of the model is shown in Appendix A. A revision of the wiring design was made during mast acceptance testing to place the drive motors in a generator mode when a limit switch operates. This was required to prevent the inertia of the rotating retraction mechanism from continuing mast movement through a power off distance and re-energizing the drive motors. The motors in a generator mode provide good braking of the mast movement.

3.2 Mast Test Procedure and Setup

3.2.1 Mast Straightness

The straightness of the mast was determined by the method indicated in Figure 5. This method involved the following steps.

a) The canister base was secured to a ground plate, and the sides of the canister were plumbed.

b) A plumb line was attached to the top plate of the mast approximately halfway between two longerons and at the edge of the top plate. The line attachment position was verified by measuring the distance d_F to the flat side of the mast.

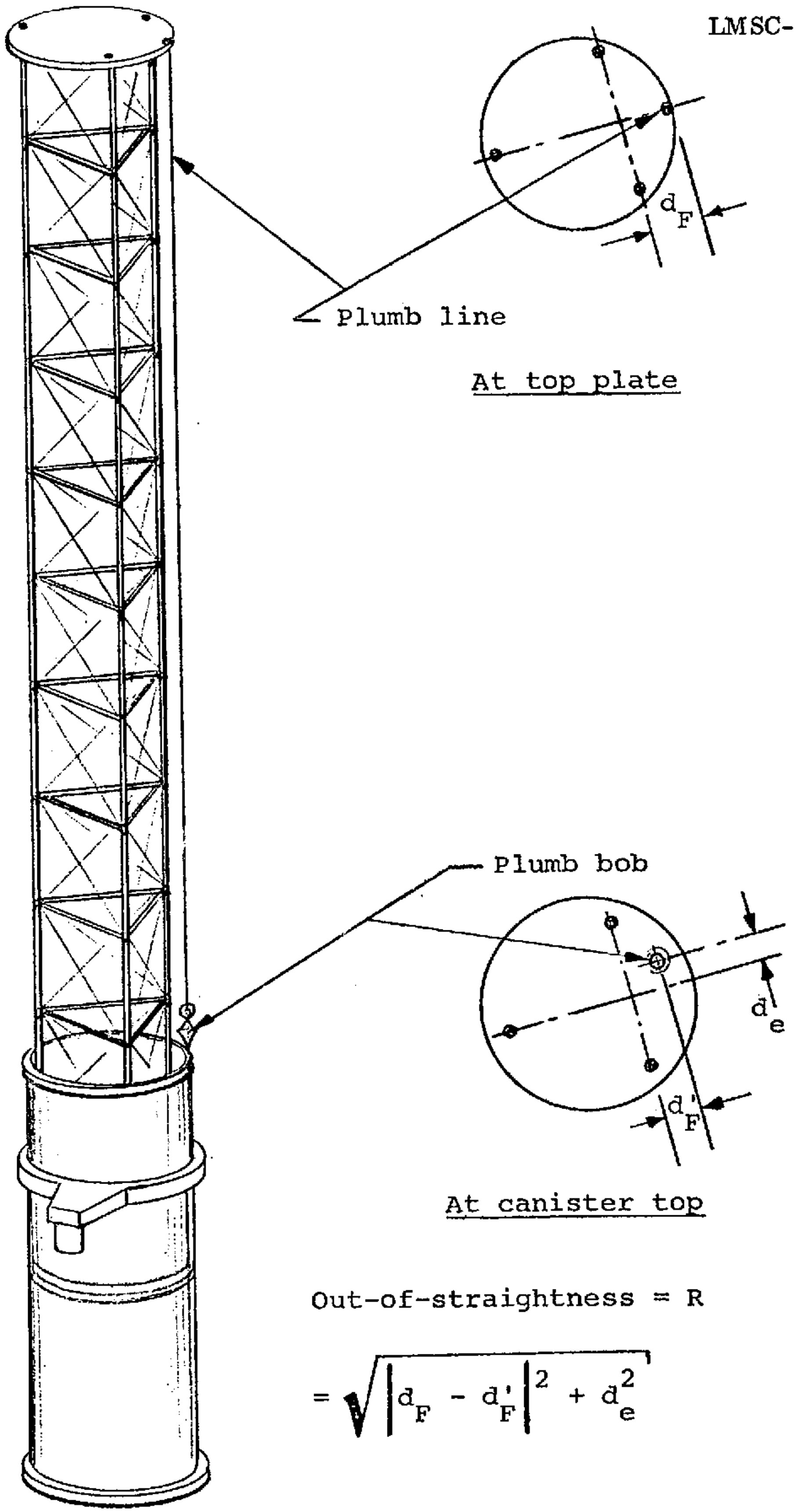
c) The mast was extended to 12 ft. (until the limit switch stopped extension).

d) The distances from the plumb bob to the flat side of the mast, d'_F, and from the plumb bob to the centerline halving the mast, d_e (see Fig. 5) were measured. These distances were also measured at the top of the canister. The out-of-straightness of the boom axis, R, is:

$$\sqrt{\left| d_F - d'_F \right|^2 + d_e^2}$$

3.2.2 Extension Tests

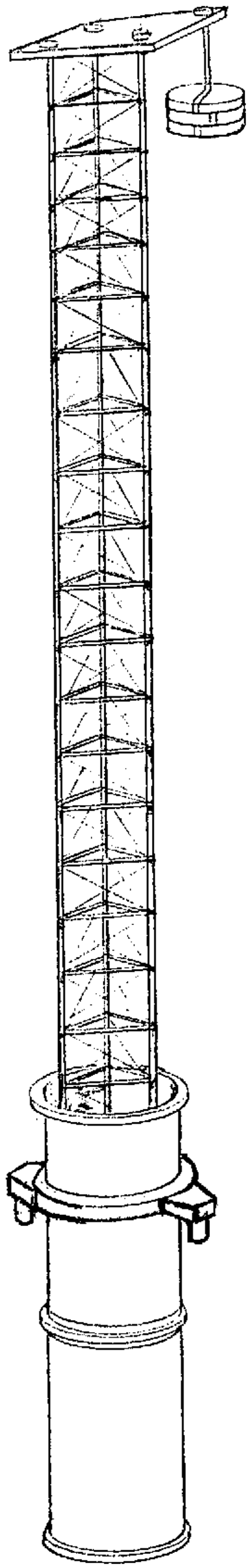
These tests were performed to demonstrate mast load capability mast extension rates and the controllability of these rates. Seven extension tests were performed, each consisting of one complete extension and retraction. The test setup is illustrated in Figure 6.



Out-of-straightness = R

$$= \sqrt{\left|d_F - d_F'\right|^2 + d_e^2}$$

Figure 5 Method for Measuring Mast Straightness



Top plate weight = 1.931 lb
Weight of hardware centered on mast = .046 lb

For Run Nos. 3 and 4, $W = 7.392$ lb
$W_c = .161$ lb
$a = 8.01$ in

For Run Nos. 5, 6, and 7, $W = 27.040$ lb
$W_c = .513$
$a = 6.66$ in

Rhombic plate 1/4-in. thick

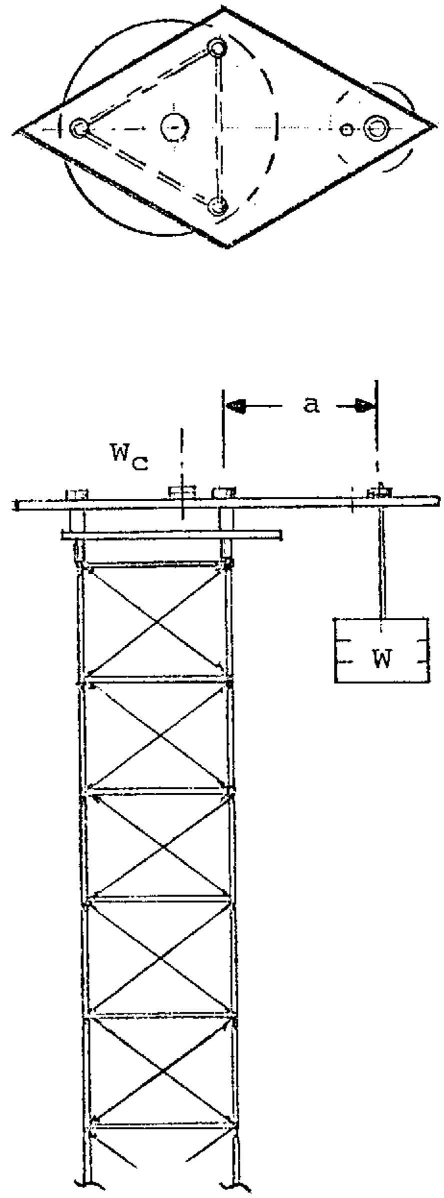


Figure 6 Setup for Mast Extension Tests

The first two extensions were performed with only a lightweight top plate as the mast tip load. The purpose of these deployments was to insure that the mast was vertical and that the limit switches performed correctly. 12V to the mast extension motors was used for the first test and 27V was used for the second test.

The next two extensions were performed with a top mass of 10 lb. applied at a distance of 6 in. outside a flat face of the mast. The purpose of these 10-lb. test shall be to demonstrate that the model can extend and retract at rates of 1 to 4 in./ sec and operate with an offset load.

The final three extensions were performed with a top mass of 30 lb. applied 6 in. outside a flat face of the mast.

These 30-lb tests demonstrated that the mast meets the strength requirements, and established the rates at which the mast extends and retracts (for the same applied voltages) under this heavier load.

The procedure for the extension tests was as follows. The voltage to the mast motors was selected on the power supply. The appropriate loads were attached to the mast tip and the runs were made. The motor voltage, motor amperage, extension times and retraction times were recorded for each run.

The mast in the test configuration is shown in Figure 7.

3.3 Mast Test Results

The no-load out of straightness of the mast at 12 feet was 0.1 in.

The mast deflections, R, observed during the tests are shown in Table 3.

The results of the deployment tests are shown in Table 4. The average observed bending stiffness of the mast element plus canister was 2.77×10^6 lb-in^2. A longeron failure occurred during the first Run No. 6 near full extension under the 30 lb. offset tip load. The longeron, one of the two nearest the load, delaminated between two bays at two locations at about 4 ft. and 8 ft. above the canister. The longeron failure was

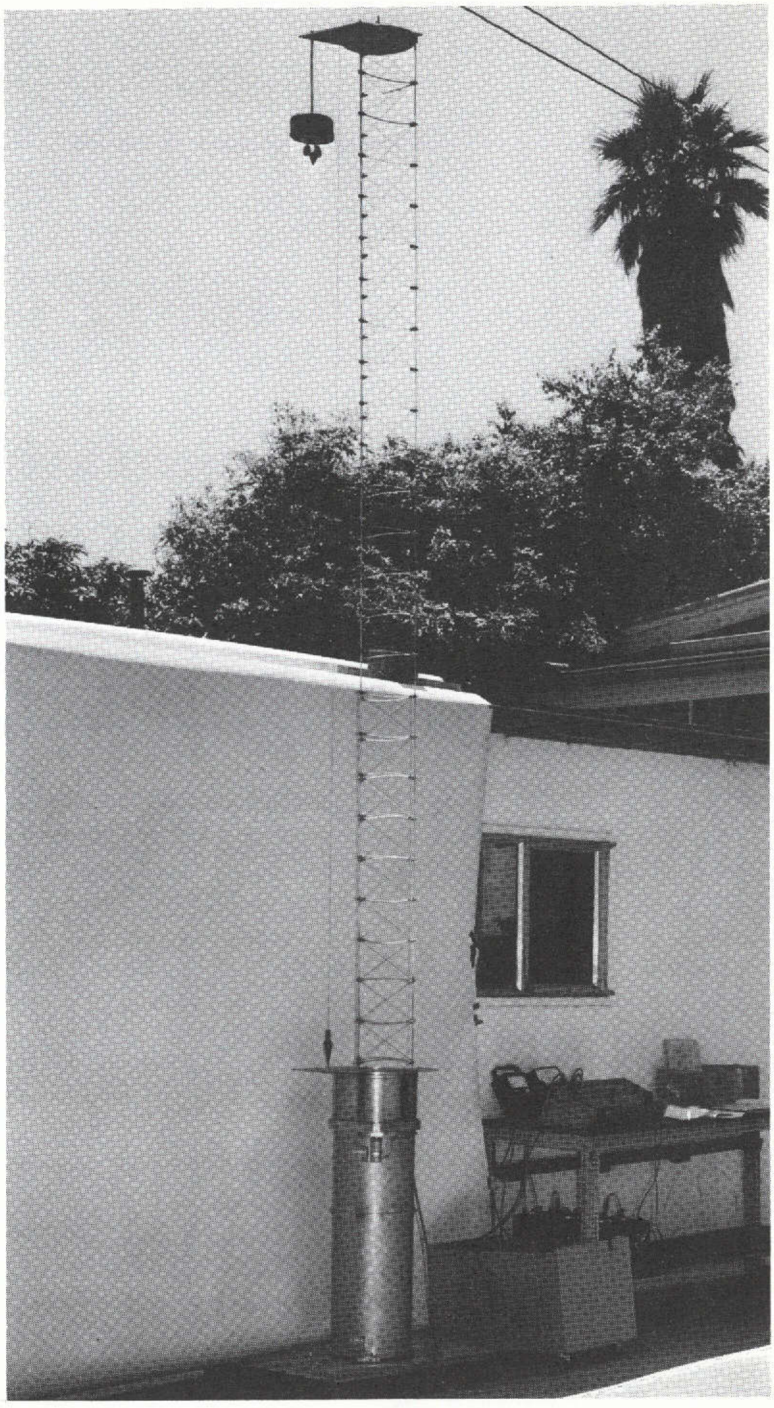


Figure 7 Extension Mast Testing

TABLE 3

MAST DEFLECTION TEST RESULTS

(12 FT EXTENSION)

Run No.	Load, Offset 6 in.	$d_F - d_F'$ (in)	$d_e - d_e'$ (in)	Deflection, R (in)
1	No-load	0.08	0.06	0.10
2	No-load	0.08	0.06	0.10
3	10	0.61	0.06	0.61
4	10	0.31*	0.06	0.32
5	30	1.10	0.10	1.10
6	30	1.4	0.50	1.49**
7	30	1.3	0.30	1.33

* Mast height = 111 in.

** Mast repaired following longeron failure during first Run #6

TABLE 4

DEPLOYMENT TESTS

Run No.	Tip Load Offset 6 in. (lb)	Applied Potential (V)	Measured Current for Extension/ Retraction (A)	Extension Time (sec)	Extension Rate (in./sec)	Retraction Time (sec)	Retraction Rate (in./sec)
1	0	13	0.8-1.4/1.0-1.6	81.2	1.77	78.2	1.47
2	0	27	1.2-1.6/1.5-1.8	30.0	4.80	31.2	4.62
3	10	15	1.2-1.8/1.2-1/8	72.6	1.98	61.5	2.34
4	10	27	0.8-1.4/1.2-1.5	24.6	4.51	22.8	4.87
5	30	19	2.6-3.2/9.8-1.7	78.1	1.84	51.2	2.81
6**	30	26	3.2-3.8/ --	47.0	3.06	Not measured	--
7	30	25	3.7-4.2/ --	50.0	2.88	34.6	4.16

* To and from 111 in.

** Mast repaired following longeron failure first Run #6, Run #1 repeated to check straightness.

believed due to a roller in that longeron not properly engaging the vertical guide rails leading to the deployment helical cam. The roller was not in the cam and the associated longeron was not sufficiently supported. Deflections of a washer on the longeron fittings at most bays on the three longerons and wear on the Delrin guide rail entrances was also observed. The longeron was replaced, the guide rail entrances were faired by removing some material and spacers were installed to provide support for the longeron fitting washers. Following repairs, Run No. 1 was repeated to check mast straightness and canister plumb, Run No. 6 was repeated and Run No. 7 was completed successfully.

4.0 ELECTRICAL MODULE TESTING

4.1 Examination

Two SEPS Solar Array Model electrical modules of 765 solar cells each and a smaller separate module of 255 solar cells were measured and weighed. The dimensions and weights of these modules are shown in Table 5.

The average weight of a 765 cell module (1/4 panel) in the SEPS Solar Array preliminary design is 701 gms. Due to design differences in the amount of on-array padding on alternating half panels, the design 1/4 panel weights are 693 gms-vertical padding strips, 710 horizontal padding strips, and 677 gms-no padding. The predicted weight of the SEPS model 1/4 panel with no padding was based on measured weights of panel components and a calculated weight of copper interconnect. The predicted increases over the design weights are shown in Table 6.

The copper foil used in the model was 1 oz. since this material was available from Somers Thin Strip (Olin Brass) in a rolled annealed form with their P-24 anti-tarnish treatment which LMSC has found to be easily laminated in thicker foils. This copper thickness at 20 percent area in the substrate would provide the design weight interconnect. Further evaluations of 1 mil versus 1.3 mil copper are of interest in the areas of:

1. Laminating electro-deposited vs rolled foil
2. Weldability
3. Manufacturing and handling of flexible array substrates

The CMC-122-1/2-1/2 (Kapton plus high temperature polyester adhesive) film material weighs 5.4 percent more than the calculated design value.

The average weight of the array model 6 mil fused silica cover (2 x 4 cm) obtained from Heliotek is 3.6 percent heavier than the design value.

TABLE 5

ELECTRICAL MODULE DIMENSIONS AND WEIGHTS

Item	Measured Value	Predicted Value
Blanket Module No. 1 (no on-array padding)		
Overall length	78.5"	78.5"
Overall width	14.82"	14.8"
Cell area length	73.90"	74.02"
Cell area width	14.19"	14.196"
Module weight	714 gms	709 gms
Blanket Module No. 2 (with horizontal on-array padding)		
Overall length	78.48"	78.5"
Overall width	14.8"	14.8"
Cell area length	73.92"	74.02"
Cell area width	14.20"	14.196"
Module weight	756 gms	750 gms
Separate Electrical Module		
Overall length	27.5"	--
Overall width	17.5"	--
Cell area length	24.6"	24.64"
Cell area width	14.2"	14.196"
Module weight	254 gms	250 gms

TABLE 6

PREDICTED DESIGN AND MODEL WEIGHT DIFFERENCES

(1/4 PANEL)

MODULE NO. 1 - NO PADDING

DESIGN	MODEL	WT. DELTA-gms
1 mil Cu, 25% area	1.3 mil Cu, 25% area	+ 9.5
CMC-122-1/2-1/2 0.00735 lbs/ft^2	CMC-122-1/2-1/2 weighed 0.00775 lbs/ft^2	+ 3.0
0.276 gms/6 mil cover	Heliotek covers weighed 0.286 gms	+ 7.8
0.0446 gms/adhesive per cell	0.060 gms/adhesive per cell	+11.8
		+ 32.1

MODULE NO. 2 - HORIZONTAL PADDING (RTV-41)

DESIGN	MODEL	WT. DELTA - gms
Same as Module No. 1		+ 32.1
RTV Padding Strips 0.0220 gms/in	RTV Padding weighed 0.0276 gms/in	+ 8.3
		+ 40.4

The model solar cells (8 mil, 2 x 4 cm wraparound contact cells), built by Centralab, all exhibited a degree of curvature along the 4 cm dimension with none observed along the 2 cm direction. The major portion of the cell contact metallization was completed in an electroplating bath at higher than room temperature and the cell curvature at room temperature is attributed to differential thermal contraction of the cell and the "P" contact. Greater cell curvature is seen with thicker "P" contacts. An average of 35 percent more adhesive was used with these cells than the design amount during the filtering process to assure adhesive voids were eliminated. Flat or nearly flat cells are required to obtain the design adhesive weight. Further investigations of the cell contact thickness control and the contact application method are indicated.

The RTV-41 padding strip design weights are based on typical properties of silicone rubber and the design configuration. As applied to the model electrical module No. 2, the padding weighed 25 percent more than the design weight. Candidate weight reductions for the padding are:

1. Interrupt present continuous strips with spaces on a 20 percent basis, or
2. Reduce cross section from 0.032 x 0.032 in. to 0.029 x 0.029 in.

Electrical module No. 2 (with RTV-41 on-array padding) actual weight is 6.4 percent heavier than the SEPS Solar Array preliminary design weight. Only the weight of the CMC-122-1/2-1/2 film appears to be non-reducible and this contributes 0.5 percent to the 6.4 percent total.

The dielectric strength of the 3 modules was measured at the closest proximity of opposite polarity interconnect material (maximum dielectric stress). This maximum stress occurs in the modules across a distance of 0.050 in. where a series string of five cells in parallel are adjacent to another series string of cells. Several readings were made at 750 vdc and the resistance measurements ranged from 1000 to 2500 megaohms. The stress was 15,000 V/in. In the full panel design the maximum stress occurs across 0.091 inches which is the separation distance between the bus bars on either side of a panel fold line. At 6 au and thus maximum module voltage, the stress is approximately 3000 V/in. The as built dielectric strength of the modules is more than adequate for the design application.

4.2 Electrical Module Illumination Testing

The three electrical modules were tested using a xenon pulse solar simulator. The test facility is shown in Figure 8. The two larger modules (15 x 78 in) were tested with a light pulse travelling horizontally. The smaller module (15 x 24 in) was tested on a table facing upward to an overhead lamp. The data obtained from the test was a module I-V curve (composed of 10 load points) and a digital recorder printout for each point (I_{SC}, V_{OC}, and 8 intermediate points) at 28°C, AMO. A data correction unit corrects the module voltage and current point values for the room temperature dialed into this unit and for the light intensity defined by the standard cell when the point data were obtained. The illumination test results are shown in Table 7 and in Figures 9, 10 and 11.

Module No. 1 was the first module welded. The solar cells used were tested bare by the cell manufacturer and grouped in three groups at 470 mv, AMO, 28°C.

1. 250 to 253.9 m.a.
2. 254 to 257.9 m.a.
3. 258 ma and above

Assuming a 2 percent cover loss, applying a calculated 0.2 percent interconnect voltage drop, the predicted module current and voltage (153 cells in series by 5 in parallel) was 1.225A at 71.77V. The measured module current at 71.77V was 1.116A. The resulting loss ascribed to welding was 7.9%. The weld schedule used was 100 ms, 0.59V, 1.5 lbs. pressure. The electrode spacing was 0.008 in. The initial weld schedule was used on 3 covered cells from the above groups and the observed current degradation at 470 mv was an average of 7.7 percent.

The weld duration was reduced from 100 ms to 40 ms but weld pull strengths were under 200 gms until the voltage was increased to 0.69V. A degradation evaluation on three covered cells using 40 ms, 0.69V and 1.5 lbs. pressure resulted in an observed current degradation of 7.4 percent at 470 mv. The second module was welded using this weld schedule while additional weld schedule evaluations were performed. The predicted performance of Module No. 2 was based on the lowest performance group cells used in this module (230 ma at 470 mv, AMO, 28°C), a 2 percent cover loss,

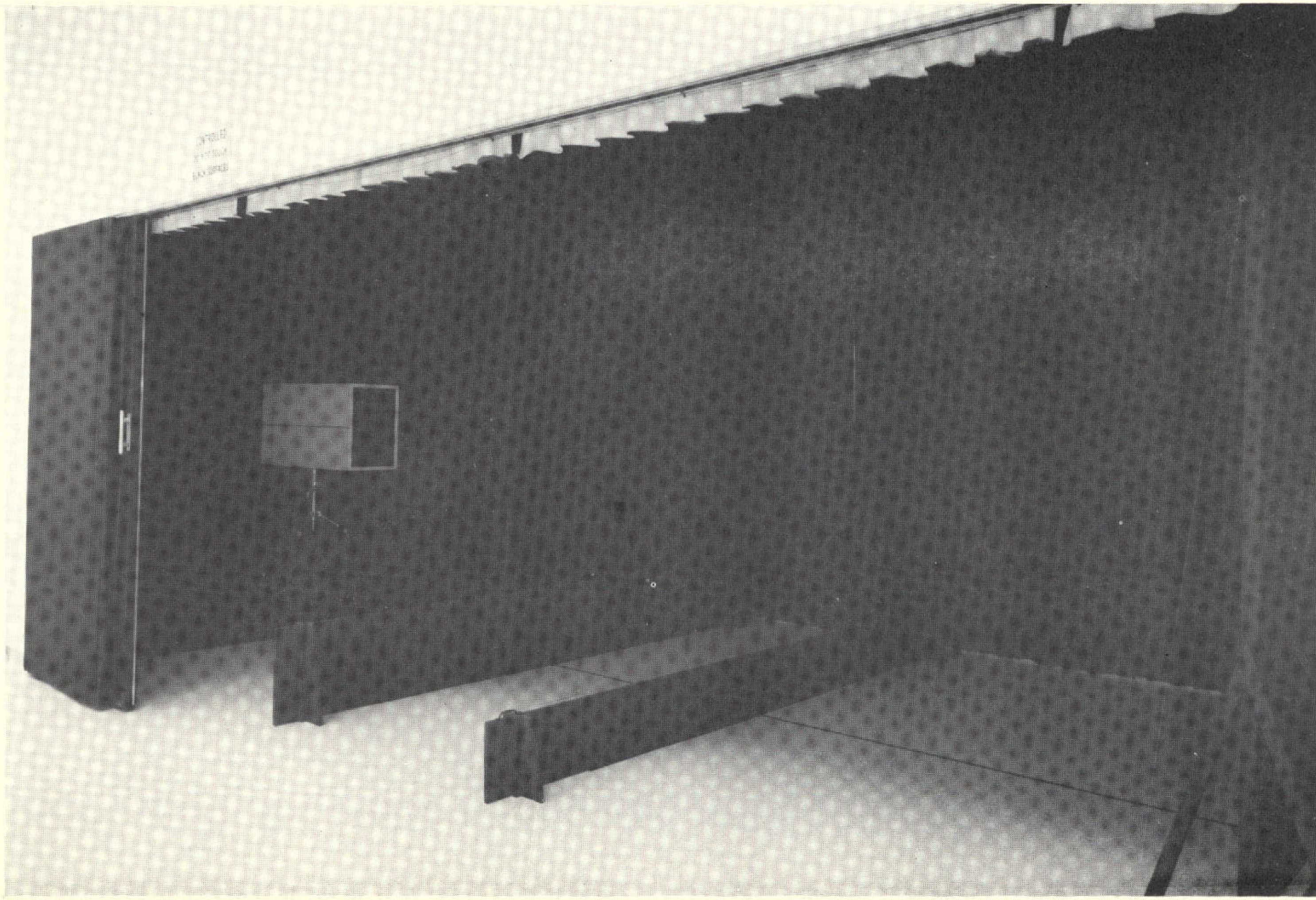


Figure 8 Xenon Pulse Solar Simulator Facility

TABLE 7

ELECTRICAL MODULE ILLUMINATION TESTING

	Load Point	Volts*	Current-* Amps
Module No. 1	1	0	I_{sc} = 1.353
	2	44.99	1.295
	3	55.99	1.255
	4	65.00	1.197
	5	69.04	1.151
	6	71.99	1.112
	7	75.03	1.037
	8	79.03	0.825
	9	81.03	0.648
	10	Voc = 85.91	0
Module No. 2	1	0	I_{sc} = 1.336
	2	44.98	1.249
	3	55.97	1.197
	4	64.99	1.123
	5	69.02	1.096
	6	71.98	1.075
	7	75.02	0.997
	8	79.01	0.831
	9	81.01	0.672
	10	Voc = 86.62	0
Module No. 3	1	0	I_{sc} = 1.375
	2	21.01	1.238
	3	22.04	1.213
	4	23.03	1.178
	5	24.08	1.129
	6	25.01	1.059
	7	26.06	0.955
	8	27.00	0.765
	9	27.99	0.501
	10	Voc=29.25	0

*Corrected to 28^{o}C, AMO

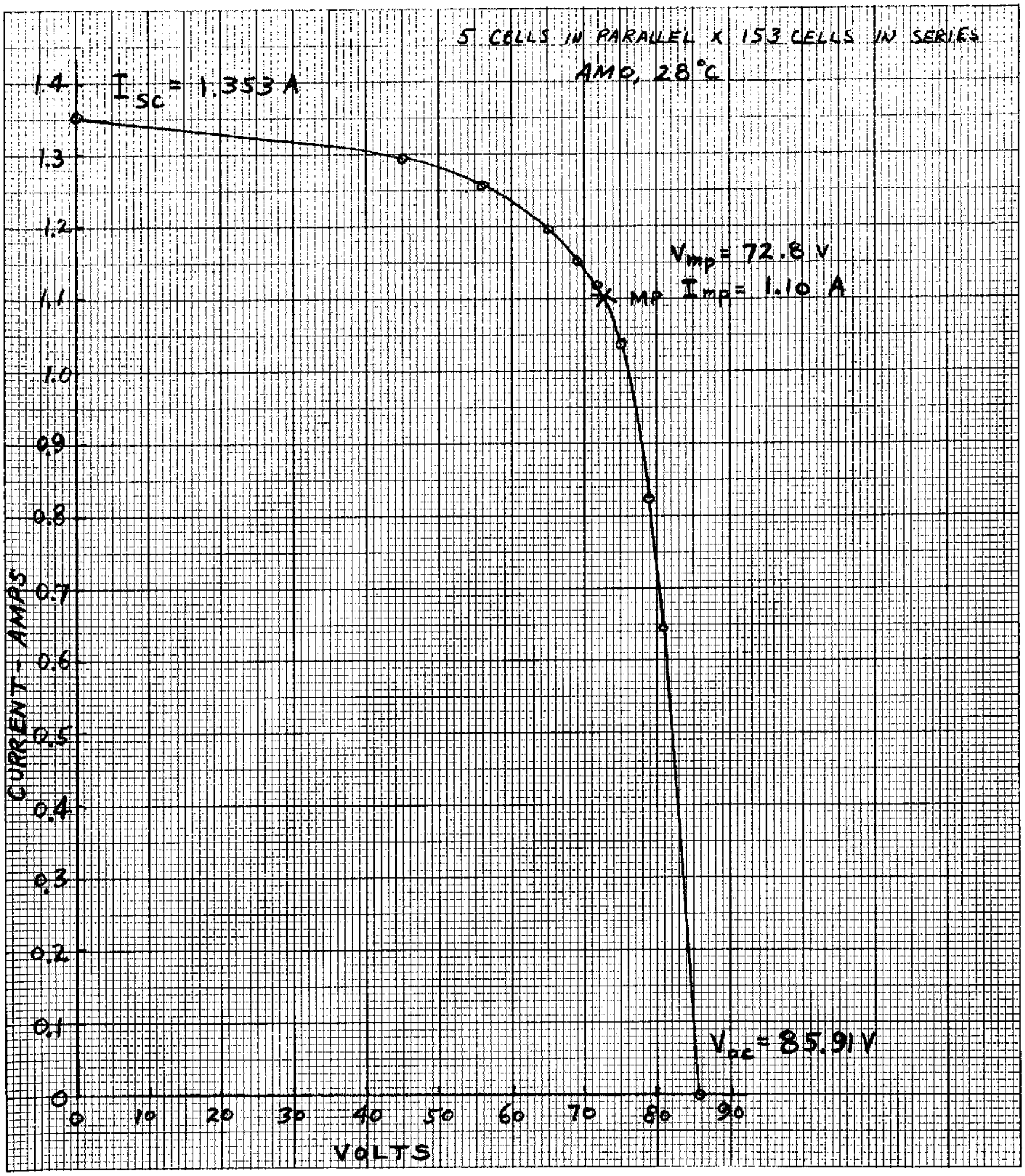


Figure 9 I-V Characteristic, Module No. 1

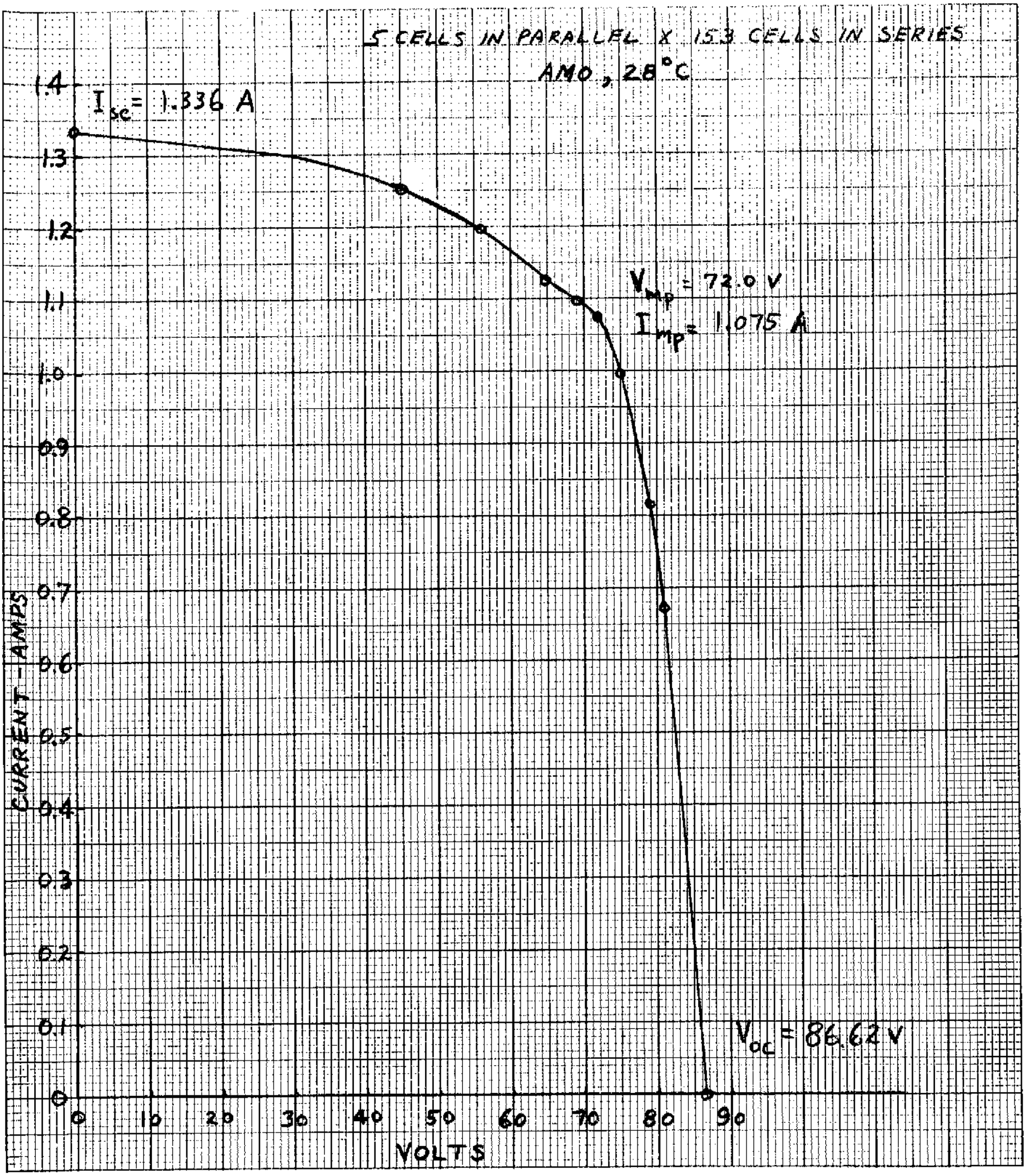
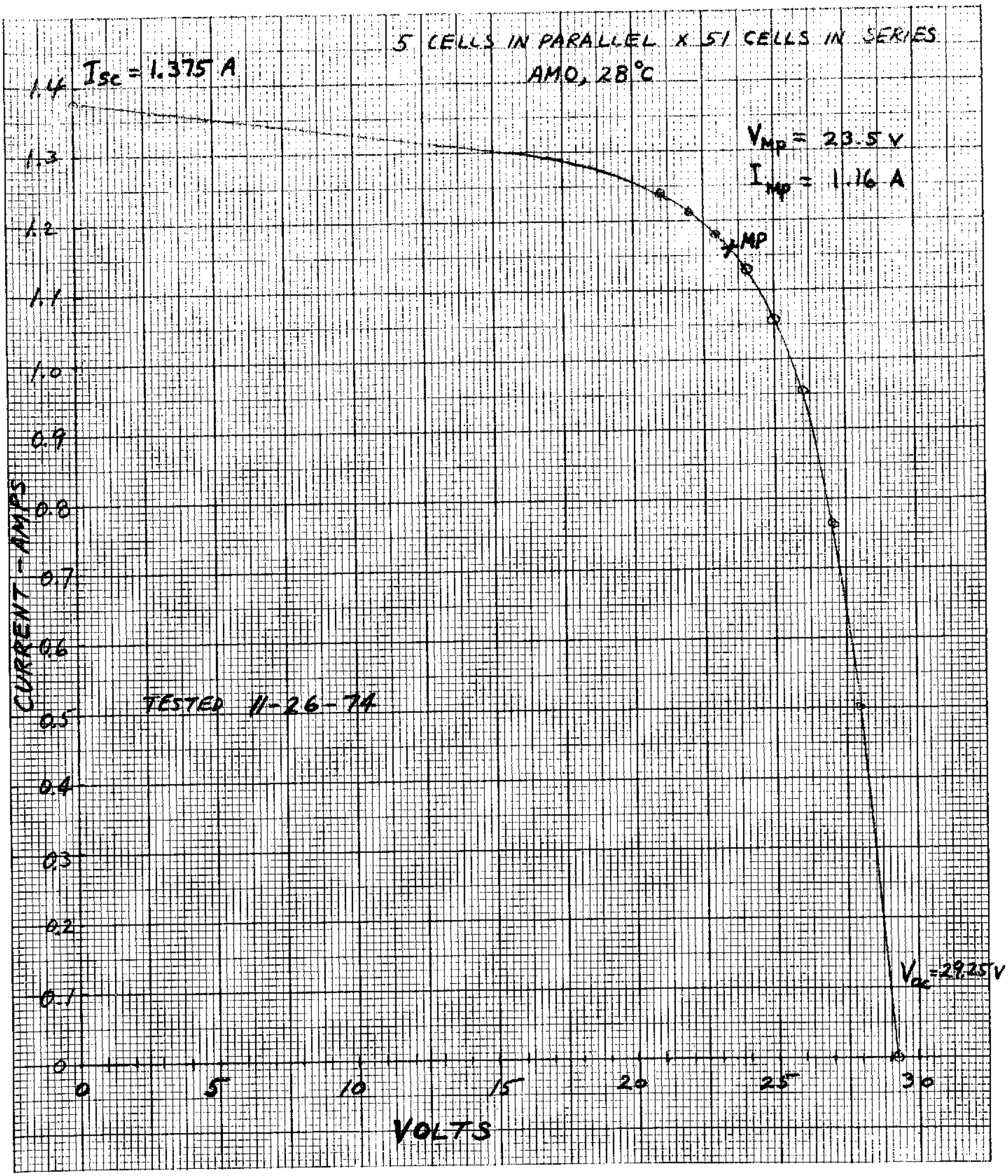


Figure 10 I-V Characteristic, Module No. 2



5 CELLS IN PARALLEL X 51 CELLS IN SERIES
AMO, 28°C
Isc = 1.375 A
VMP = 23.5 V
IMP = 1.16 A
MP
TESTED 11-26-74
Voc = 29.25 V
CURRENT - AMPS
VOLTS
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30

and a 0.2 percent interconnect voltage drop. The predicted module current and voltage was 1.127 A at 71.77 V. The measured module current at 71.77 V was 1.075A. The resulting loss ascribed to welding was 4.6 percent. The shape of the I-V curve of Module No. 2 near the maximum power point appears to indicate an open solar cell in that module and an investigation of an infrared open cell detection method is reported further on.

The additional weld schedule investigations increased the electrode force to 2.0 lbs. from 1.5 lbs. since welding investigations on another program were observing less degradation with higher electrode pressures. An evaluation of 40 ms, 0.64V, 2 lbs. force resulted in 8% average degradation and an evaluation of 50 ms, 0.62V, 2 lbs. force resulted in a 2% average degradation. This latter schedule was selected for welding Module No. 3. The predicted module current was 1.127A at 23.92V. The measured module current at 23.92V was 1.130A which indicates no welding degradation.

From the above investigations, it is apparent that optimization of the weld schedule for either the 1 oz. or 1 mil copper interconnect system is required in future work to insure no, or acceptably small, welding degradation. The above investigations were limited to one schedule applied to both N and P contacts on the wraparound cell since the avoidance of two schedules is expected to be a cost savings. Further investigation may show two schedules are required. The new design 8 mil wrap-around contact 2 x 4 cm cells used in this program were prototype cells and the contact metallization thickness control achieved by the cell vendor in the weld areas was not within the desired range. Weld schedule optimization will require further cell fabrication development.

4.3 SEPS Solar Panel Infrared Image Test

The SEPS solar array electrical module No. 2 was suspected of having one or more open cells. This module was tested in a dark thermal image test, using a Dynarad Thermal Imager. It was postulated that by driving forward current through the panel, without illumination, the solar cells passing the forward current and dissipating power would appear bright in the thermal image. A cell which was open-circuited would necessarily appear dark. The applied current was approximately 1 ampere.

In the actual test, however, the panel showed a wide variation in cell brightness, representing estimated temperatures from room temperature to several degrees above, for an applied power level of about 100 mW/cell average. Thus it was easy to distinguish several cells which were quite dark, six of which were likely open circuits. In addition, a parallel set of 5 cells appeared very dark, indicating a possible short.

Factors which can make a cell appear dark include:

- (a) open circuit
- (b) high series resistance
- (c) high cell voltage

These are factors which would make a cell draw less of the applied current than its parallel neighbors. Of these three factors, both open circuit and high series resistance can exhibit the same characteristics at the panel level, if the series resistance is very high.

It was possible to view the entire width of the panel (15 in.) and about 1/4 of the length in one image, although resolution was much better viewing a smaller area.

This test was conducted as follows:

1. The panel was scanned in vertical strips about 4 cells wide, and cells noted according to their relative darkness levels.

2. Suspected dark cells were rechecked, also using transient power dissipation to indicate cold cells.

3. Larger panel areas were viewed to compare several suspected cells wherever possible. The imager display unit has a single scan mode in which it can display the relative temperature along any horizontal line on the 2-dimensional image.

No absolute temperature reference exists within the instrument. The display adjusts its own brightness level, according to the brightness of the whole area viewed; thus no temperature comparisons could be made except within the area of a single image.

It was concluded that this type of test will certainly spot any open-circuit cell, but it will also turn up a number of other cells which are either higher than normal in dark forward voltage or higher than normal in series resistance. Applying a higher power level would indeed help discriminate the open cell. Therefore, the maximum safe power level for forward current excitation of the cells should be established, and this level applied, for best results.

The panel was placed in the sunlight and current readings were obtained for 15 different groups of 5 cells in parallel that appeared suspect in the infrared image test. One of the groups read 15 percent lower than the average value of the other groups. Inspection showed that the N contact had lifted from the silicon on one cell and that the weld joint on the other N contact was not intact. This cell was replaced.

5.0 CONTAINMENT BOX AND PRELOAD ASSEMBLY TESTING

The Containment Box and Array Blanket Preload Assembly were measured and weighed and these data are shown in Table 8. The forces provided by the 6 wires tensioned by negators were measured at three positions over their full travel length. These data are also shown in Table 8. The model array blanket assembly composed of the 4 panels, the array harness assembly, the top attach bar, the intermediate tension bar and the bottom attach bar, was weighed and assembled into the Containment Box. The four adjustable length linkages between the preload lever arms and the preload distribution hat sections (located on the box cover at the 1/4 span points) were shortened until a force of 1 pound was observed on the preload lever arm ends at the box center. This force was measured with the preload lever arms in the locked position under the rollers thus causing the box cover to compress the model array blanket and the padding on the box cover and on the box floor. The lever arm length to the roller is 41.8 in. and the distance between the adjustable length linkage and the roller is 1.3 in. Thus the individual lever arm forces are thus multiplied by a factor of 32 at the box cover hat sections. The model blanket preload was 128 lbs. over an area 15X 154 in. or an average of 0.055 lbs/in^2. The model mast (10 in diameter) has a safe retraction load capability of 14 lbs. at a distance of 14 in. from the face of the mast triangular cross-section. The model counterbalance system, the resultant of the four locking lever arm forces, and the cover assembly weight all operate on the mast tip assembly at this 14 in. position. Based on a safety factor of 2, the preliminary design calculation indicates a preload of 1.82 lbs/in^2 will be required for launching the solar array. This results in the flight design mast being required to provide 120 lbs. maximum retraction force at the 14 in. position at the near full mast retraction (full blanket preload) position. The preliminary design mast (14.6 in diameter) can provide this force.

TABLE 8

CONTAINMENT BOX AND PRELOAD ASSEMBLY DIMENSIONS AND WEIGHTS. TENSIONING SYSTEM FORCES

ITEM	MEASURED VALUE

Box overall length 157.30"
Box overall width 16.25"
Box overall height 14.39"
Box interior length 157.05"
Box interior width 16.00"
Box weight with supports and tensioning system 52.4 lbs. (w/o cover)
Box cover weight with preload assembly and mast 45.5 lbs. tip support

WIRE POSITION	GUIDE WIRE NO. 1 FORCE		GUIDE WIRE NO. 2 FORCE	
	EXTEND	RETRACT	EXTEND	RETRACT
Start motion	1.4#	1.3#	1.2#	1.1#
Mid position	1.2	1.2	1.0	1.3
Full motion	1.4	1.5	1.2	1.3
	INTERMEDIATE TENSION NO. 1 FORCE		INTERMEDIATE TENSION NO. 2 FORCE	
Start motion	1.2	1.2	1.4	1.3
Mid position	1.4	1.1	1.3	1.4
Full motion	1.2	1.2	1.3	1.2
	BOTTOM TENSION NO. 1 FORCE		BOTTOM TENSION NO. 2 FORCE	
Start motion	6.1	6.1	6.0	6.1
Mid position	6.2	6.3	6.2	6.1
Full motion	6.0	6.2	6.0	6.0

6.0 ROOT SECTION MODEL ASSEMBLY TESTING

6.1 Mast and Counterbalance System Check

The model was positioned in the support frame such that all testing was performed with the deployment mast extending in a vertical direction. The counterbalance system free running capability was checked by measuring the counterbalance force in several positions of a simulated extension and retraction of the model. The counterbalance system was attached to the box cover/preload assembly with a counterbalance weight equal to the box cover/preload assembly weight, 45.5 lbs. The locations of the counterbalance system column, pulleys and whiffletree were then adjusted to maintain the box cover centered over the containment box in a 1 "g" field. The mast operation was checked by running the mast up and down with the electrical control box and the fully extended and partially extended mast positions heights were measured and adjusted to the desired heights for the model blanket (139 in. full extension and 49 in. partial extension). The model component weights and forces that are applied to the mast are shown in Table 9. The counterbalance weight was increased from 45.5 lbs. to 54.5 lbs. so that the load on the mast at full extension is equivalent to 17 lbs. at 6 in. from the face of the mast element next to the array blanket.

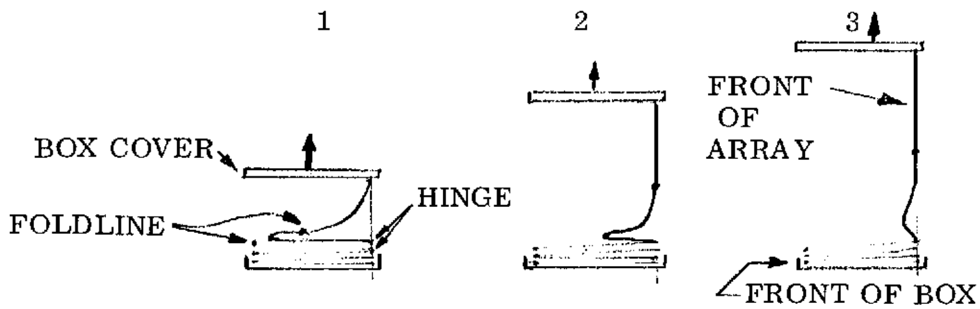
TABLE 9

MAST LOADING

Item	Weight-Lbs.
Model array blanket (includes harness and tension distribution bars)	17.8
Guide wire force (max.)	2.7
Intermediate tension force (max.)	2.5
Bottom tension force (max.)	12.5
Cover and preload assembly weight	44.0
Mast tip assembly weight	1.5
Total	81.0 lbs.

6.2 Preload Assembly and Guide Wire Operation

The mast tip assembly was attached to the box cover and preload assembly and the model was operated over the first 24 inches of mast extension and retraction. The electrical module, No. 2, is in the lower half of the top array panel. This module exhibited a small radius rolling fold line as shown below.



The mast was stopped at position (3) and four vertical Be-Cu strips 15 x 0.016 x 0.25 in. were attached to the back of the electrical module to increase the radius of the rolling fold-line during 1 "g" operations. An "N" contact on two cells were noted to have separated from the substrate interconnect. The electrical module, No. 1, is in the upper half of the top array panel. The upper half of the array panels do not experience a fold line movement and no damage was experienced by this module.

At the start of retraction, the fold line on the top panel did not tend to move toward the front of the containment box along the full 157 in. blanket width. Manual assistance was required to guide the fold line forward until the box cover is down to about 6 in. above its final position. The Be-Cu stiffeners in the bottom half of the panel assisted in causing the fold line to fall at its forward position.

The guide wires and the array harness (aluminum FCC) operated as designed.

The preload locking mechanism (See Figure 12) operated satisfactorily during release and extension but the mechanism frame, which was designed to be deflected by cams on the box, could not be adjusted for reliable hands-off operation. It either self-deflected before the cover was low enough for locking or was compressed by the mast in a

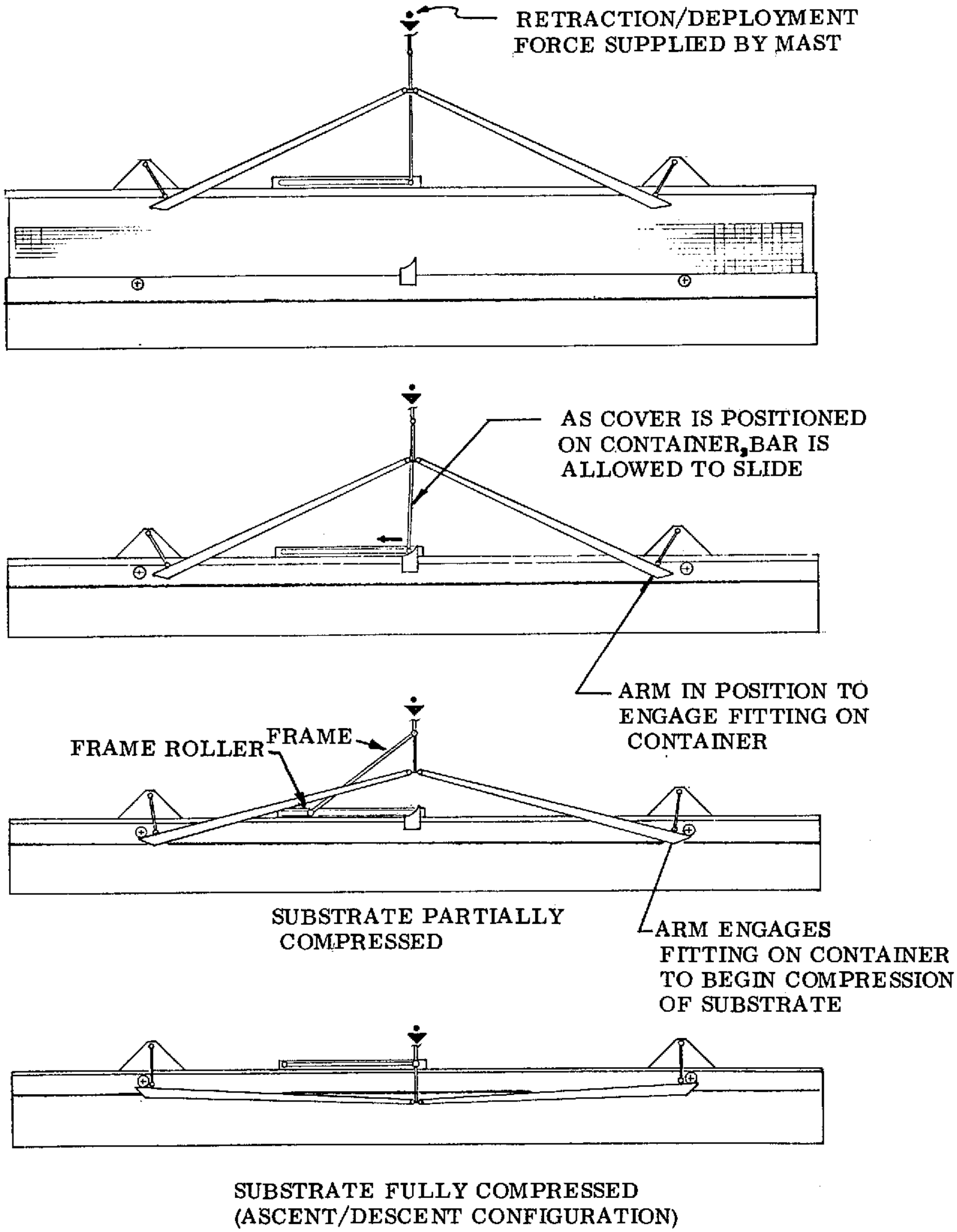


Figure 12 Rolling Frame Locking Mechanism

vertical position before the cams acted on the frame rollers. The mechanism that allows the mast to actuate the locking lever arms, when the box cover is in the closed position, was redesigned (See Figure 13) and the desired "hands-off" locking operation was achieved. The frame lower end was pinned to the cover at the center of the cover and a knee was introduced in the center of the frame. A spring acting at the knee tends to keep the knee open in a vertical position even as the folded array starts to resist the lowering of the box cover. This spring force is overcome only when a mechanical cue (two projections on the box itself) strikes a trip on the bottom of frame, causes the knee to collapse in the right direction, and allows the mast to operate the locking lever arms. The mechanical cue is positioned such that cover locking action does not occur unless the four locking levers are in position to go under the four rollers that the levers act against.

The 24 inch extension-retraction operation was repeated two more times. Two solar cells were observed to be separated from the interconnect system after both extensions on Module No. 2. No glass simulator breakage, solar cell or solar cell cover breakage was observed.

6.3 Array Extension and Tensioning System Operation

The array blanket was extended from full retraction to the first intermediate extension position. This position was with one panel, the top panel, fully extended. The intermediate tension distribution bar was integrated with the hinge between the top panel and the one below it during assembly of the model array blanket. The guide wire and intermediate tension wire systems operated correctly. One solar cell was observed to be separated from the interconnect system on Module No. 2 and the two cells first observed to have one "N" contact joint broken were both observed to now have 3 of the 4 cell joints broken. The extended panel assumed a good planar configuration.

The array was extended from the intermediate extension position, 49 in., to the full extension position, 139 in. The guide wire, intermediate tension and full tension wire system operated correctly. The array planar configuration was good overall, but small local waviness was observed over much of the solar cell simulator panels. This waviness is attributed to the 0.032 in. diameter steel wire used as the hinge pin between panels which retains some bends from its initial coiled packaging which were not completely removed. Some waviness is also attributed to slight variations in the straightness and parallelism of the five hinge lines involved in the four panel blanket configuration. These dimensional variations are caused by manual operations in the fabrication of the panel hinges and can be greatly reduced with the development of more tooling than was used to fabricate the model.

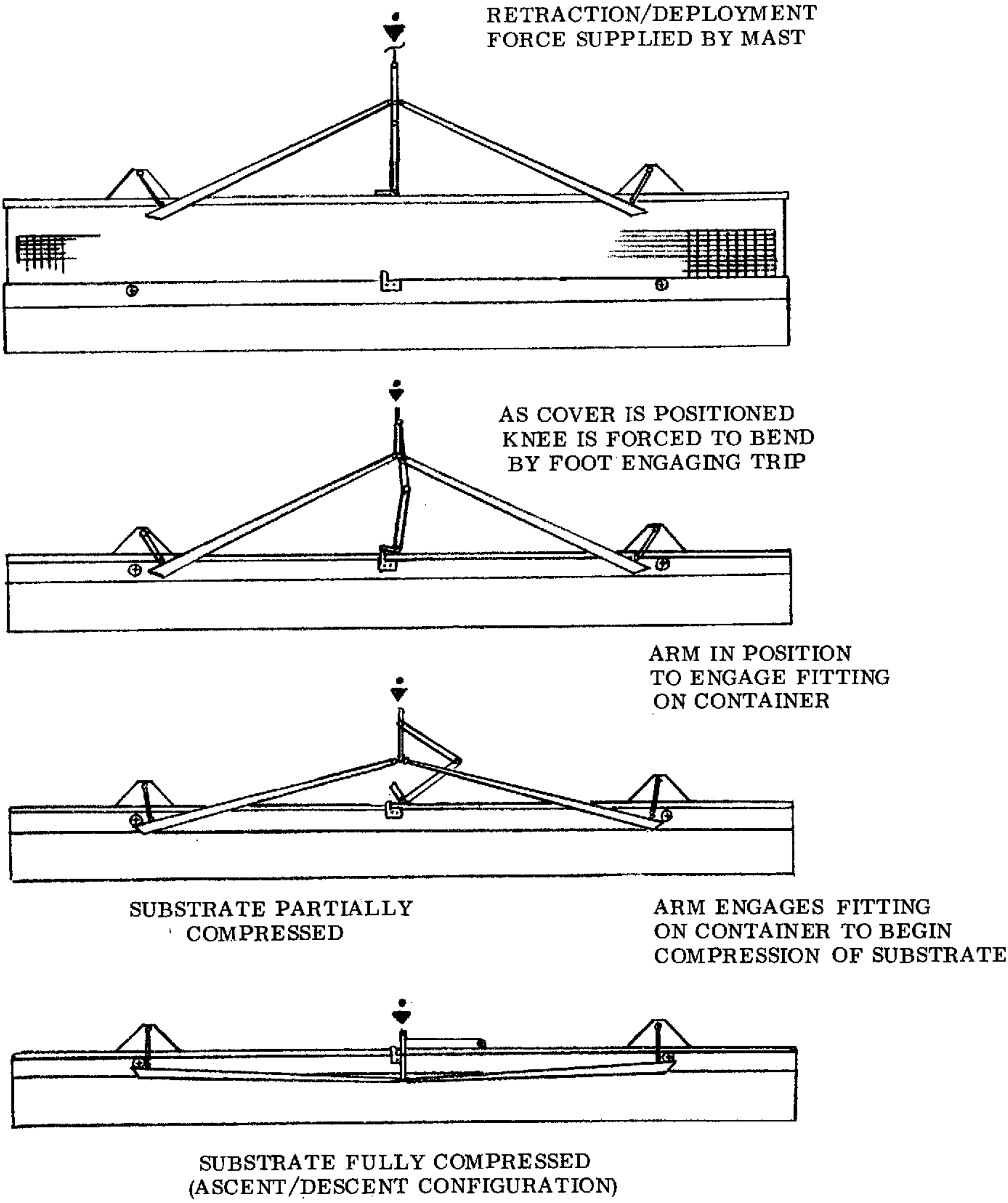


Figure 13 Collapsing Knee Locking Mechanism

The local waviness, moving from crest to crest, runs in a horizontal direction and is therefore not removed by the tension put into the blanket by the tensioning system or the blanket's weight in the 1 "g" field. It is believed that if horizontal variations of blanket tension that result from two tension wires leading to one tension distribution bar tended to cause waviness in the model blanket, then this effect would be masked in a 1 "g" field due to the weight of the model blanket. It was also observed that the electrical modules hang in a flatter manner than do the simulator panels because the electrical substrates with the printed circuit copper interconnects are stiffer than the solar cell simulator panels which use 2 mil Mylar film as the substrate.

The array was retracted to the intermediate position and then to the fully retracted position. The tensioning system wires and the tension distribution bars retracted properly. The blanket preload was applied automatically and the mast partial retraction and full retraction limit switches operated properly. The model extension mast operating characteristics during this test series are shown in Table 10. It was originally planned to run the model deployment tests at a slow speed at first and build up to an intermediate speed and finally to a high speed. The counterbalance system and the varying loads on the mast, as the weight of the blanket supported by the mast increased, required that the full nominal motor voltage, 28 vdc, be used to prevent stalling the motors after an extension height of 3 to 4 feet was reached. During retraction operations, the use of a motor voltage over 15 vdc resulted in a retraction rate that was too fast for proper manual assistance to control the movement of the panel foldlines to the front of the array containment box. These two voltage values provided proper operation and control, and were used for the model deployment tests.

6.4 Second Partial Extension Position Testing

An important objective of model testing was to demonstrate the changing of the intermediate deployment position to a new position with proper model operation. The hinge pin which joined the top panel to the panel just below was removed while the containment box cover was about 6 inches above the containment box. This released the intermediate tension distribution bar hinge loops and the hinge pin was reinstalled to join the two panels. The hinge pin in the middle of the four panel blanket was removed and reinstalled with the intermediate tension distribution bar hinge loops

TABLE 10

MODEL DEPLOYMENT TESTS

Movement	Preload Value (lbs)	Motor Potential (V)	Motor Current (A)	Mast Height (in.)	Time (sec)	Mast Movement Rate (in/sec)
Full closed to intermediate position	128	28	1.8-2.2	49	14.0	3.5
Intermediate position to full extension	--	28	2.0-2.8	139	28.1	3.2
Full extension to intermediate position	--	15	1.3-1.9	49	47.4	1.9
Intermediate position to full closed	128	15	1.4-2.0	0	27.2	1.8

integrated into the panel hinge line. The cam, located on the mast batten, that actuates the intermediate mast position limit switch when the correct mast height is reached, was moved to the proper batten and the limit switch position in the mast canister was adjusted. The model was then closed fully and the deployment tests were repeated. The resulting mast operating characteristics are shown in Table 11. No new solar cell or glass simulator damage was observed. The proper operation of the model was observed except that several guide wire grommets were damaged. The grommets were made of an FEP Teflon impregnated cloth loop glued to a 0.1 x 0.1 x 0.040 in. aluminum square that contained a hole for the guide wire. The cloth loop was held by the hinge pin between array panels. These loops had been abraided by the intermediate tension distribution bar. The six grommets in the model were replaced with small wire loops that were relatively loosely wrapped around the hinge pin and the guide wire to prevent binding of the guide wire.

6.5 Repair and Additional Tests

The solar cells which had fallen off the interconnect system (5) and the two which were almost off (3 of 4 cell joints off) were replaced on the blanket using a solder joining technique. The SEPS Solar Array Root Section Model was extended and retracted two more times prior to shipping the model to NASA/MSFC. The model operation was proper with the exception that during the last deployment two solar cell simulators on the no-array-padding side of the blanket were observed to be cracked. These simulators were on panel nos. 2 and 3, the middle two panels.

TABLE 11

MODEL DEPLOYMENT TESTS

Movement	Preload Value (lbs)	Motor Potential (V)	Motor Current (A)	Mast Height (in.)	Time (sec)	Mast Movement Rate (in/sec)
Full closed to intermediate position	128	28	1.6-2.2	79	21.4	3.7
Intermediate position to full extension	--	28	1.8-2.4	139	18.2	3.3
Full extension to intermediate position	--	15	1.2-1.6	79	35.3	1.7
Intermediate position to full closed	128	15	1.2-1.8	0	49.4	1.6

APPENDIX A
MAST ELECTRICAL CHECKS

The results of visual and resistance checks are shown in Table A-1. The mast control electrical circuitry is shown in Figure A-1.

TABLE A-1
ELECTRICAL CONTINUITY AND FUNCTION

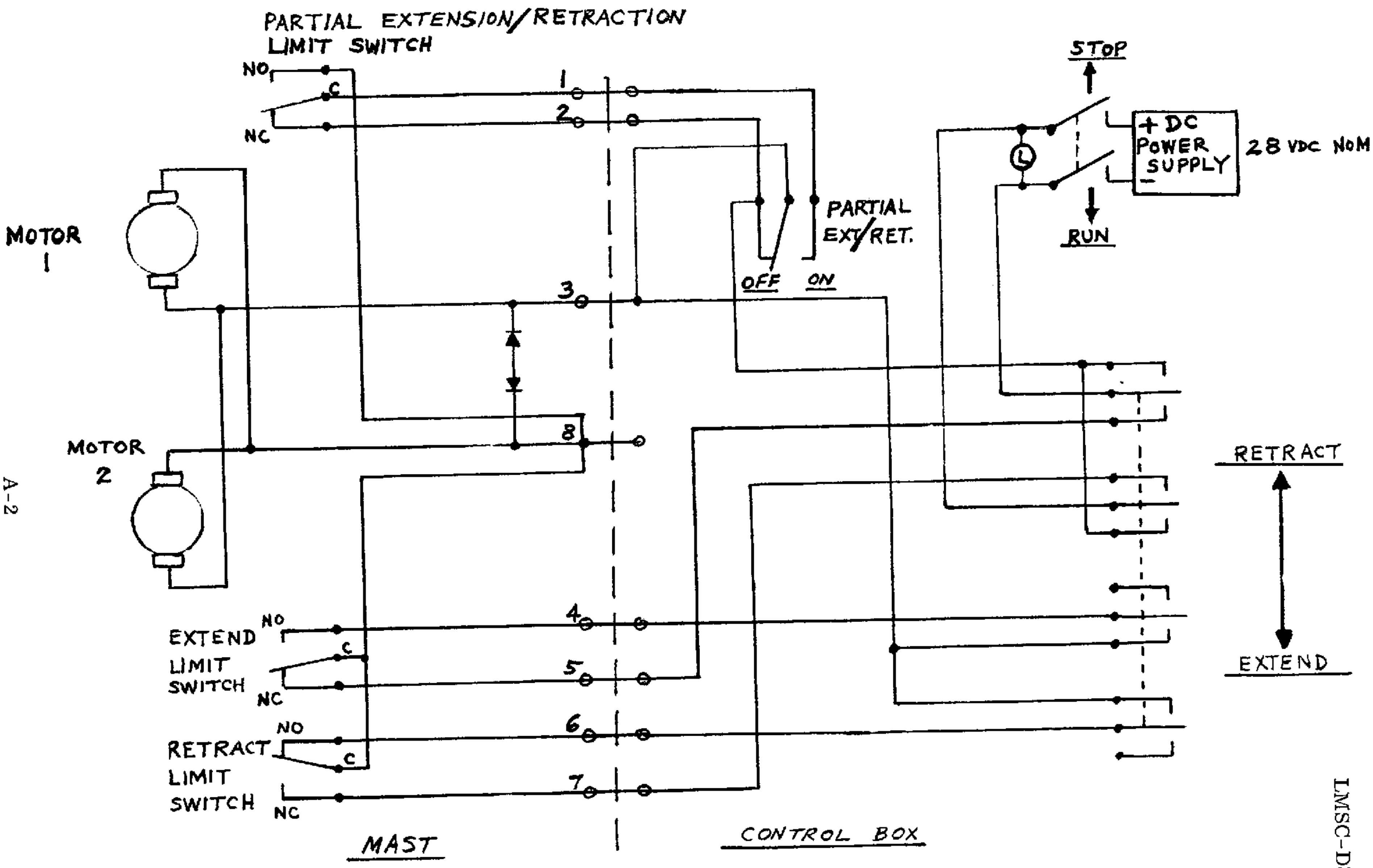
Terminal Number	Lead To	Resistance - ohms -	Visual Check
1	Partial-extension limit switch: common	0.01	
2	Partial-extension limit switch: NC terminal	0.01	
3	Motors 1 and 2: red lead	--	X
3	Diode from Terminal 8	--	X
4	Extension limit switch: NO terminal	0.01	
5	Extension limit switch: NC terminal	0.01	
6	Retraction limit switch: NO terminal	0.01	
7	Retraction limit switch: NC terminal	0.01	
8	Motors 1 and 2: black lead	--	X
8	Diode from terminal 3	--	X
8	Partial-extension limit switch: NO terminal	0.01	
8	Extension limit switch: common	0.01	
8	Retraction limit switch: common	0.01	

Limit-Switch function

Retraction switch: Open = 1.4 ohms (6 to 8); Closed = 1.4 ohms (7 to 8)

Extension switch: Open = 1.4 ohms (4 to 8); Closed = 1.3 ohms (5 to 8)

Partial-extension switch: Open = 1.3 ohms (1 to 8); Closed = 1.4 ohms (1 to 2)



NOTE: MAST FULLY RETRACTED

Figure A-1 Model Electrical Schematic